Controllers and Pilots Play a Key Role in Runway Safety Initiatives Through Real-Time Simulation

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ABSTRACT

A new and innovative way to evaluate runway safety initiatives for airports is through the use of interactive real-time simulation. The National Aeronautics and Space Administration (NASA) operates an integrated suite of simulators that can give both pilots and tower controllers the ability to simultaneously "try out" ideas in the safety of virtual reality. In February of 2003, the Federal Aviation Administration (FAA) conducted a demonstration in the NASA facilities for Dallas/Fort Worth International Airport (DFW) of a concept to reduce runway crossings and enhance the efficiency of the airport. Currently, DFW experiences about 1,700 runway crossings per day, which contribute to arrival and departure delays. In addition, each runway crossing introduces the potential for a runway incursion. The proposed concept included the addition of new perimeter taxiways on the East and West sides of the airport. Through use of NASA's unique simulation capabilities, DFW controllers and commercial pilots provided expert feedback on the safety and operational implications by directly experiencing the proposed changes in a high-fidelity simulation. Overall, the data collected from the participants and the simulators demonstrated that the concept would improve operations at DFW, if implemented. Improvements were observed in many areas including departure rates, taxi duration, runway crossings, and controller and pilot communications.

INTRODUCTION

The Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) are committed to enabling increases in the safety and capacity of major national and international airports. Many research and development efforts are being planned, and the agencies have identified the need to have Certified Professional Controllers (CPCs) and airline pilots play key roles in many of these safety initiatives. An integrated suite of cockpit and air traffic simulators at the NASA Ames Research Center (ARC) in Moffett Field, California, provides a unique opportunity to allow the pilot and controller communities to directly assist the FAA and NASA in developing and evaluating new ideas to improve airport and airspace safety and capacity.

At the heart of NASA ARC's collection of simulators is FutureFlight Central (FFC) – a full-scale, 360-degree control tower simulator [1] (see Figure 1). The high-resolution 3D visual representation allows an entire airport to be simulated and operated in all types of weather and lighting conditions. The full-scale tower cab allows all controller positions, including the Supervisor and Traffic Management Coordinator (TMC) positions, to be staffed. Ramp and Terminal Radar Control positions can also be staffed to further enhance the realism of the control tower operation. A staff of "pseudo-pilots," responding to controller instructions, has operated traffic scenarios at rates upwards of 270 operations (arrivals and departures) per hour. Controllers are able to operate their airport with anticipated future traffic levels and fleet mix or with modifications such as additional runways, taxiways, or terminals. Real-time simulations at FFC offer the unique ability to visualize and control airport traffic for a proposed airport modification long before any concrete is poured, or before any operational changes are implemented.

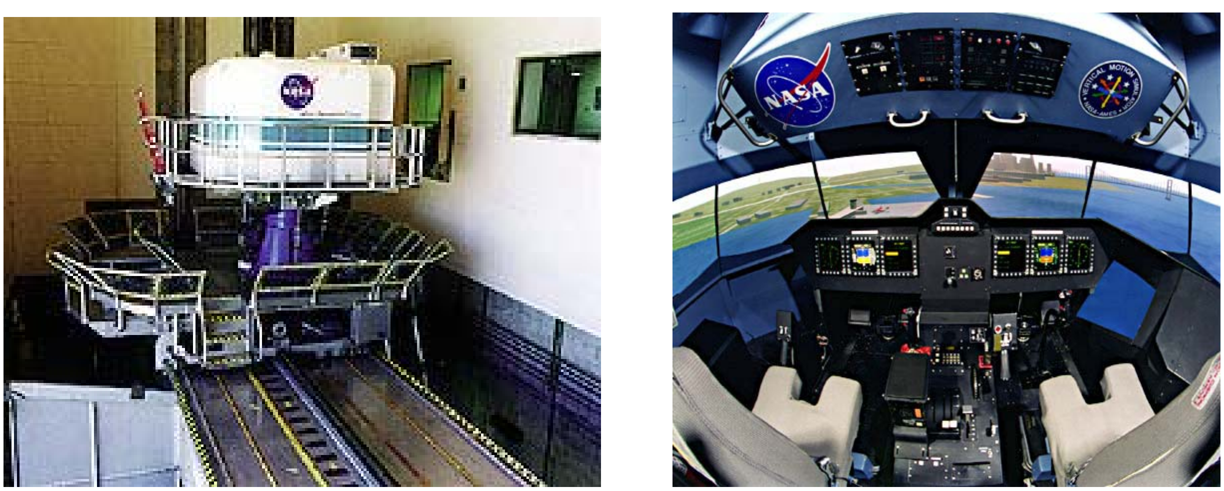
Figure 1. FutureFlight Central Tower Cab

The pilot community is able to experience physical and operational changes to an airport by flying in the cockpit simulators available at NASA ARC. The Crew Vehicle Systems Research Facility (CVSRF) is a unique national research facility dedicated to aviation human factors and airspace operations issues and their impact upon aviation safety. The CVSRF includes two flight simulators: a Boeing 747-400 and an Advanced Concepts Flight Simulator (ACFS) (see Figure 2). Both simulators feature a full six degree-of-freedom motion system, a 180° field of view, and a digital sound and aural cueing system. The visual system can depict out-the-window scenes in day, dusk, night, and twilight modes. The B747-400 simulator is a fully detailed replica of a current airline cockpit and is constantly maintained to the highest level of certification (i.e., Level D) for airplane simulators as established by the FAA. The ACFS is configured as a generic commercial transport aircraft employing many advanced flight systems as well as features existing in the newest aircraft being built today.

a) Boeing 747-400 Cockpit Simulator　　b) Advanced Concepts Flight Simulator

Figure 2. Crew Vehicle Systems Research Facility Cockpit Simulators

The Vertical Motion Simulator (VMS) is another six degree-of-freedom airplane simulator at Ames, and its 60-foot vertical and 40-foot lateral motion capability makes it the world's largest motion-base simulator (see Figure 3). The operating philosophy of the VMS is to support the widest range of aeronautical research. The system can be configured by selecting and integrating the most appropriate of several interchangeable components to suit the specific requirements of any simulation. Vehicles simulated by the VMS range from the Shuttle Orbiter and military fighters to various experimental fixed-wing and rotorcraft designs.



a) External Cab on Motion Track　　b) Cockpit Interior

Figure 3. Vertical Motion Simulator

These simulators (i.e., FFC, CVSRF, and VMS) are able to interactively distribute aircraft information (e.g., location, orientation, speed, and altitude) among themselves via the industry standard High Level Architecture (HLA) protocol. In this way, aircraft in an FFC simulation can be seen from the cockpit of either of the flight simulators. Conversely, an aircraft representation from either of the flight simulators can be seen from the tower (or radar) within an FFC simulation. Controllers and pilots can communicate directly on the installed digital voice communication systems. This ability to actively involve both controllers and pilots in an interactive, simultaneous simulation was what brought the FAA and DFW to NASA ARC in June 2003.

BACKGROUND

<u>The DFW Demonstration</u>

Currently, DFW experiences about 1,700 runway crossings per day, which contribute to arrival and departure delays and introduce the potential for a runway incursion. The existing configuration at DFW requires that aircraft arriving on the East-side Runway 17C-35C cross the departure Runway 17R-35L, and aircraft arriving on 17L-35R cross both the arrival Runway 17C-35C and the departure Runway 17R-35L. The aircraft arriving on Runway 31R must also cross both Runways 35C and 35L. Similarly, the aircraft arriving on the West-side Runway 13R must cross both the arrival Runway 18R-36L and the departure Runway 18L-36R, and aircraft arriving on 18R-36L must cross the departure Runway 18L-36R. Figure 4 depicts the DFW runways, terminals, three control towers, and existing taxiways and bridges.

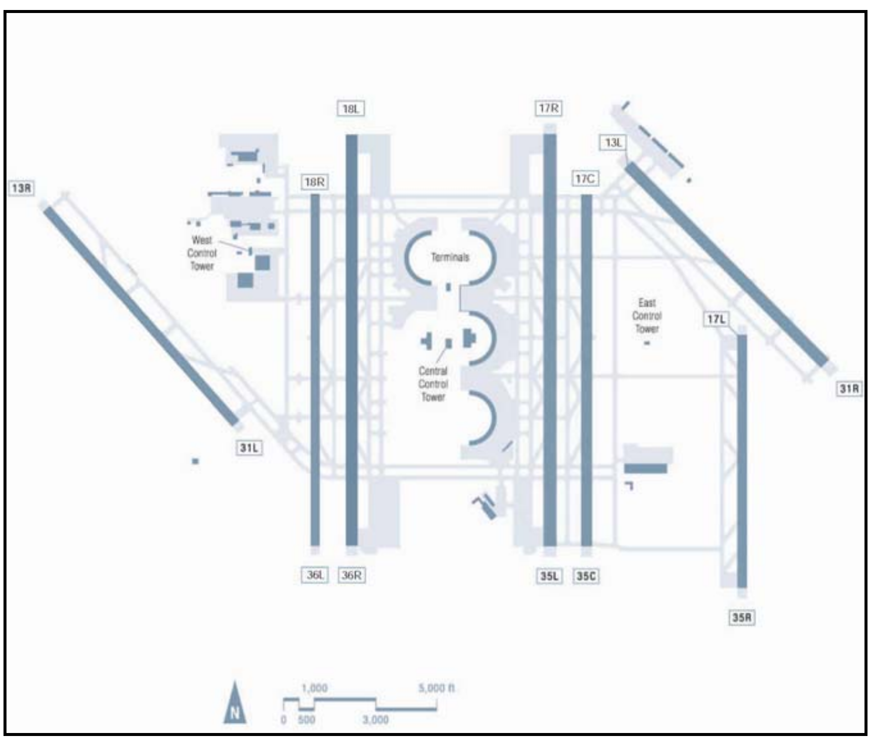


Figure 4. Existing DFW Configuration

Under current operations, the local controller must conduct all runway crossings before the aircraft can be released to the ground controller. This situation increases the local controller's workload in meeting airport demand mainly due to frequency congestion and challenges the local controller to fully utilize the available runways. During major arrival and/or departure pushes, tradeoffs are sometimes made to safely balance all operations. During periods of high departure demand, arriving aircraft can be delayed waiting for clearance to cross the inboard (departure) runway because the controller must open a "gap" in the departures to allow time for arriving aircraft to cross. Similarly, when arrivals stack up at the various runway-crossing points departures are delayed to accommodate these crossings. These situations are most evident during the peak traffic times.

In an effort to enhance DFW operations by reducing arrival and departure delays and to significantly reduce the runway incursion potential by eliminating runway crossings, a perimeter taxiway (PT) concept was proposed. The concept includes new PTs on the East and West sides of the airport and two new high speed exits each on 17C and 18R. Figure 5 shows an aerial perspective of the proposed new PT concept.

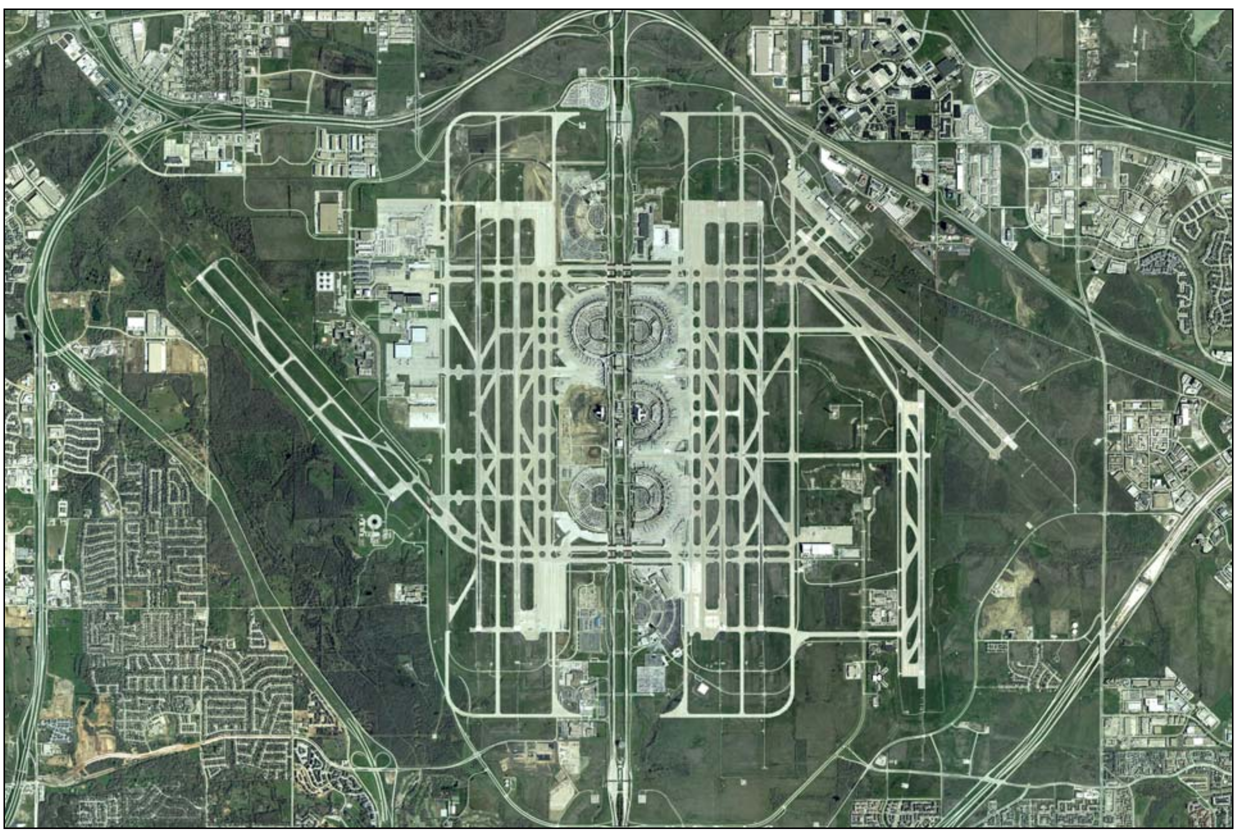


Figure 5. DFW with Proposed Perimeter Taxiways

Many fast-time simulations and paper studies have been conducted that support the cost benefit, efficiency, and safety aspects of the proposed airport improvements. However, prior to the Dallas/Fort Worth International Airport Perimeter Taxiway (DAPT) Demonstration, the improvements had not been observed or assessed in an operational setting using real-time simulation with human operators. Therefore, a partnership effort involving DFW, the FAA, and NASA was formed to conduct a real-time human-in-the-loop simulation that demonstrated the effect of adding new PTs to DFW. The DAPT Demonstration was conducted in February 2003 using two of NASA ARC's unique simulation facilities (i.e., FFC and CVSRF). Scientists from the FAA William J. Hughes Technical Center in New Jersey acted as Principal Investigator and provided support for the research team.

The primary objective of this endeavor was to provide the airlines, CPCs, pilots, and their associated unions the opportunity to observe and participate in a demonstration of the proposed airport improvements, at high-fidelity levels, with the goal of gaining their acceptance of the PT concept at DFW. In particular, there were four "views" of special interest for the demonstration: 1) the controller view, 2) the pilot-on-taxi view, 3) the pilot-on-arrival view, and 4) the pilot-on-departure view. The secondary objective was to collect and analyze operational data from the simulations for the purpose of comparing baseline and perimeter taxiway data for runway occupancy times, taxi times, and pilot and controller transmissions.

Participants

Certified Professional Controllers

Five CPCs from DFW participated during the four days of demonstration. All CPCs were current on the airspace and airfield simulated. During Baseline (BL) conditions, two local controllers, one cab coordinator, and two ground controllers operated the traffic. During PT conditions, two local and three ground controllers operated the traffic.

Pilots in the B747-400 Simulator

Pilot participants from several airlines operating out of DFW acted as either the First Officer or observers during the demonstration. There was one First Officer position and two observer seats available in the cockpit. Two to three pilots participated per day over a 3-day period for a total of seven pilot participants.

Simulation Support

Pseudo-Pilots

Though not the subject of evaluation, approximately 25 trained pseudo-pilots supported the FFC operation. Pseudo-pilots emulated all pilot communications and actions (except for those associated with the B747-400 simulator). They initiated air-to-ground communications, and responded to ATC instructions. The pseudo-pilots used a graphical interface to view the airport and surrounding airspace, and for entering aircraft control instructions.

Research Facilities and Equipment

FFC

The tower cab simulator supplied all controller and pseudo-pilot positions for the demonstration. A digital voice-communication system (e.g., radios, headsets, telephones and interphones) was used by the simulation participants to interact in real-time. FFC recorded the simulations (audio and visual) for playback. Surface movement metrics such as taxi times and runway crossings were collected and reported for each run. Video monitoring of activities in the tower cab during simulations were also recorded for post-simulation playback and analysis.

CVSRF

The flight deck was simulated using the high-fidelity CVSRF Boeing 747-400 simulator. Pilot participants either flew in the First Officer position or experienced the operations from one of the observation seats in the cab. The six degree-of-freedom motion feature was used throughout the demonstration.

Scenarios

Traffic operations from the East Tower were simulated for daytime, south-flow conditions. Traffic scenarios were created using current DFW operations data modified to create future demand levels and the desired traffic mix. The arrival and departure rates for both BL and PT reflected future demand levels of DFW operations that exceeded current peak demand by approximately 20 to 30%. The fleet mix represented a realistic projection of the fleet mix for the 2003-2006 time frame. The percentage of regional jets (RJs), Boeing-757s, and heavy aircraft was increased, and the percentage of large jets (non-RJs) and turboprops was decreased.

All traffic samples were designed to last approximately 45 minutes. Three basic traffic scenarios were created that were similar in schedule and complexity to allow for comparisons. Each traffic scenario was used to simulate BL and PT conditions. In addition to these traffic scenarios, one training scenario was created for use in three training runs. The environment simulated for all scenarios was daytime visual meteorological conditions (VMC) with a ceiling of 5000 ft and 5 miles visibility.

Experimental Conditions

Two operational and taxiway configurations were considered; 1) *Baseline (BL) Operations* used the current DFW operational environment, procedures, and taxiways, and 2) *Perimeter Taxiway (PT) Operations* used a new operational environment with PTs and revised operational procedures.

Method

ATC

The first day of the demonstration was dedicated to briefing CPCs on the study background. They were instructed on airspace structure, airport configurations, perimeter rules and procedures, and the laboratory equipment and configuration. In addition, the participants reviewed demonstration questionnaires so they became familiar with the information that was to be collected from them throughout the demonstration.

CPCs then participated in three 45-minute training runs that represented configurations and environments similar to BL and PT conditions. The participants had the opportunity to rotate through positions during training. This gave them an opportunity to become familiar with the new configurations and procedures, experience the simulated environment, and ask questions as needed. Data collection runs began after the training runs were completed.

The study consisted of 13 data collection runs. Runs included repetitions of BL and PT conditions. The controllers rotated positions between each run. The study was designed such that an individual controller would not work the same traffic scenario from the same position more than once. Conditions were randomized to avoid learning and order effects.

Flight Deck

Pilots participated in the demonstration from inside the B747-400 simulator for 3 of the 4 days. Each pilot was involved in the demonstration for one day. The B747-400 simulator was originally planned to be configured via a two-way link to the FFC tower; however, due to technical issues and a shift in the demonstration objectives, a one-way link was used. Therefore, the pilots were able to see the airport traffic from the FFC simulation in the B747-400 cockpit, but the B747-400 was not visible or audible to the controllers in FFC. Each day, the pilots experienced three to five unstructured "Free Form" runs that lasted approximately 45 minutes. Pilots rotated positions after each run. The flight crew was given a menu of options from which they selected to experience a variety of conditions of interest. Menu items included such options as an arriving flight passing over taxiing traffic on the perimeters, a departing aircraft passing over taxiing traffic on the perimeters, an engine-out departure, instrument flight rules or visual flight rules conditions, day or night environments, and eye point adjustments to simulate elevations of different aircraft types.

Data Collection

Subjective and objective data were collected from the CPC participants. Subjective data included post-run questionnaires, post-simulation questionnaires, and debrief sessions. Questionnaires inquired about CPC experiences with perimeters, traffic realism, and other details. The objective data included taxi time durations, various arrival and departure data, runway occupancy times, inbound and outbound taxi statistics, runway crossing data, and pilot and controller communications data.

Participating pilots provided subjective data, which included post-simulation questionnaires and debrief interviews that elicited information about their experiences and opinions.

RESULTS AND DISCUSSION

There were 13 data collection runs in the demonstration that included six BL runs and seven PT runs. In general, the subjective and objective data demonstrated that the PTs would improve operations at DFW if implemented. The results revealed many interesting distinctions between the BL and PT conditions. However, because this was a demonstration, it is imperative to recognize that all results should be used and interpreted with caution.

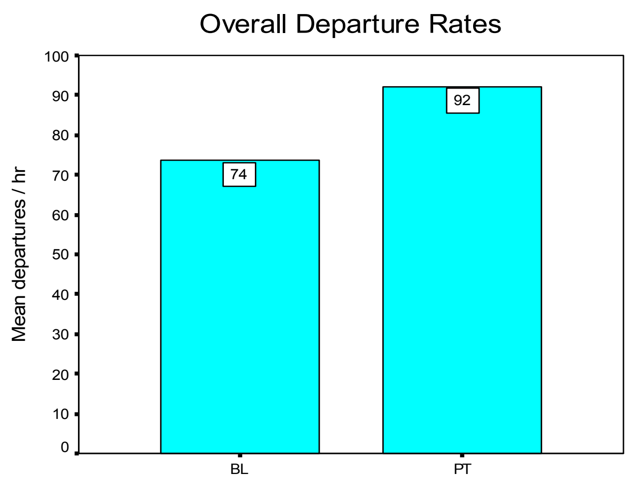
Subjective Data

All controller and pilot participants agreed the demonstration was a good representation of operations at DFW and the proposed new taxiways, and all perceived a marked improvement from BL to PT conditions. The participating controllers believed that the implementation of PTs in the demonstration enabled an overall more efficient operation. They felt the PTs provided for a smoother flow of traffic, afforded better ability to move aircraft to and from the runways, improved situation awareness, and decreased workload demands. Pilot participants thought the PTs improved efficiency and increased safety by reducing the potential for runway incursions. They also speculated that PTs would improve airline performance rates and reduce both pilot and controller workload due to less frequency congestion and a reduction in hold-short instructions.

Objective Data

The objective data resulting from the demonstration supported the participants' verbal comments. These data also indicated that the PTs would improve operations at DFW if implemented.

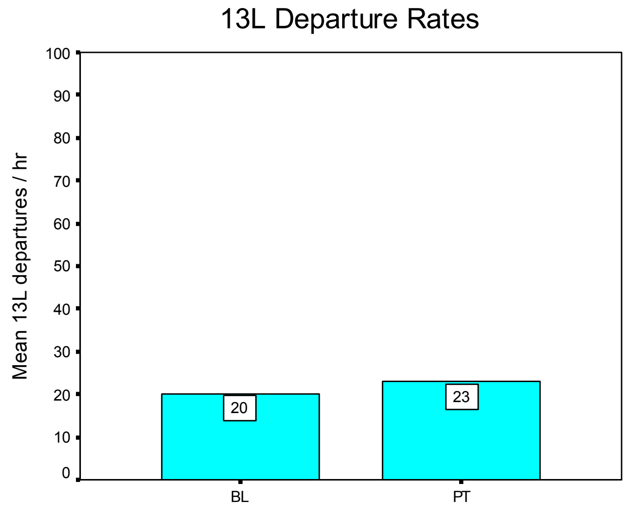
Mean arrival rates for BL and PT conditions remained consistent (by design) at about 79 aircraft per hour. However, Figure 6 indicates a substantial increase of about 18 departures per hour on average (or 24% relative increase) in the departure rate for the PT condition on the East-side runways.



% Change BL to PT	+ 24 %

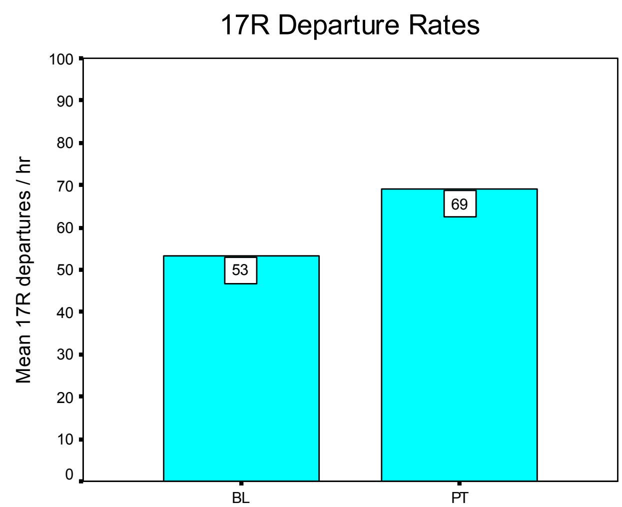
Figure 6. Overall departure rates (East-side of DFW)

There was an average increase of three departures per hour on 13L with PTs (a 15% relative increase), but the difference seen in the overall departure rate on the East side was mostly due to the substantial improvement on 17R, which increased 16 departures per hour on average (a 30% relative increase). Figures 7 and 8 illustrate these findings.



% Change BL to PT	+ 15 %

Figure 7. Runway 13L departure rates



% Change BL to PT	+ 30 %

Figure 8. Runway 17R departure rates

The average inbound taxi duration per aircraft increased by about 2:07 minutes (or 18%) from the BL to the PT condition. Looking at the data by runway, it appears that the increase was due exclusively to the marked increase in 17C taxi duration times (4:56 minutes, or 54% increase over BL). In fact, during PT conditions, 17L taxi durations actually decreased by about 1:16 minutes or 8% on average.

The average outbound taxi duration and associated runway occupancy times showed improvements with PTs compared to BL runs, as did inbound and outbound stop rates and duration times. The average outbound taxi duration and associated runway occupancy time (when behind a heavy jet) showed substantial improvement with PTs compared to the BL conditions, decreasing on average 4:28 minutes (27%) and 41 seconds (44%), respectively. Runway occupancy time for departures (when not behind a heavy aircraft) showed a decrease of about 4% with PTs. On the whole, inbound stop rates and the duration of stops decreased substantially when PTs were available (-49% and -28% respectively). The average outbound stop rate decreased by about 14% for PTs runs, and the average duration of these stops were 29% shorter than in the BL runs.

BL runs averaged 154 runway crossings an hour (about 94 aircraft crossed 17R per hour and 60 crossed 17C per hour). By design, PTs completely eliminated runway crossings at DFW in the demonstration.

Controller and Pilot Communications

Controller and pilot communications for the most critical frequency were clearly reduced with the addition of PTs. On the Local East-1 (LE1) frequency, there were significantly fewer transmissions (22% relative reduction) and fewer words spoken (27% relative reduction). This resulted in the controllers and pilots spending less time on frequency (24% relative reduction) when compared to BL runs. Words were also spoken slightly slower on average during PT runs. In addition to being operationally relevant, these results were also statistically significant for the LE1 frequency. Such findings were consistent with controller debrief comments; controllers felt that the volume of communications was significantly reduced and that they used less verbiage because concerns about crossings and reliance on pilot readbacks were alleviated. Many of the positive data results were also apparent in the findings of the other frequencies, but generally to a lesser degree.

Demonstration Conclusions

Based on the results of the data collected from the demonstration, it is clear that the stated objectives of the exercise were successfully met. The controllers and pilots were afforded the opportunity to observe and experience the proposed airport improvements with a high degree of realism and fidelity. Despite the fact that this exercise was a demonstration, a considerable amount of data was available for analysis. The results revealed many interesting distinctions between the BL and PT conditions. However, because it was a demonstration and not a formal experiment, it is imperative to recognize that all results should be used and interpreted with due caution.

In conclusion, all controller and pilot participants agreed the demonstration was a good representation of operations at DFW and the proposed new taxiways. They perceived a marked improvement from BL to PT conditions and felt that the addition of PTs improved efficiency and reduced potential for runway incursions. The objective data supported controller feedback, indicating that PTs would be advantageous to operations.

FINAL COMMENTS

NASA and the FAA are working together to revolutionize air traffic management for the National Airspace System (NAS). The simulation facilities at NASA ARC are playing a significant role in this endeavor through the Virtual Airspace Modeling and Simulation (VAMS) Project. NASA's concept for a new air transportation system envisions large increases in the movement of people and cargo, including manned and unmanned vehicles, small aircraft, and reusable launch vehicles. Revolutionary concepts will need to be rigorously tested to select those that are the most beneficial. The Virtual Airspace Simulation Technology (VAST) Project, one cornerstone of the VAMS project, is charged with providing the means for testing the new concepts through advancements in simulation and modeling. Real-time distributed simulation will ensure that human performance and human factors studies can be performed to better understand human and system interactions. A series of tests demonstrating connectivity among NASA ARC simulation facilities have been ongoing since November 2002 and are scheduled to continue over the next few years.

Distributed simulations are ideal for controller and pilot training, human factors research, the evaluation of new hardware or software in the tower or in the cockpit, and the development, testing, and evaluation of new airport procedures or physical changes to the airport geometry. The realism and safety of the simulation environment is ideal for conducting these types of tasks and gathering valuable data and insight.

The DAPT Demonstration and VAMS Project are good examples of how controllers and pilots can play key roles in runway safety initiatives using real-time simulation techniques and the unique facilities at NASA ARC. Clearly there are many research and safety initiatives that the FAA, NASA, and other organizations can explore through this powerful suite of research tools.

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BIOGRAPHICAL SKETCHES

Mike Madson is a Project Manager for FutureFlight Central at NASA Ames. He has worked at NASA since receiving his degree in Aeronautical Engineering from Cal Poly, San Luis Obispo, in 1982. Prior to joining FFC in 2000, he was involved in both computational and experimental aerodynamics research.

Kim Bender earned a B.A. in Behavioral Science and an M.A. in Forensic Psychology. She currently works as a Human Factors Specialist for Titan Corporation and has supported the FAA William J. Hughes Technical Center since 2000. She expects to graduate with an M.S. degree in Human Factors from Embry Riddle Aeronautical University in 2004. Her human factors research experience includes usability assessment, experimental design, real-time human-in-the-loop simulation research, and project management.